PORT ARRANGMENT FOR A ROTARY VALVE ENGINE

TECHNICAL FIELD

The present invention relates to a means of improving the volumetric efficiency of an axial flow rotary valve internal combustion engine. It is applicable to all internal combustion engines incorporating hollow cylindrical axial flow rotary valves, where the rotary valve accommodates one or more ports terminating as openings in the valve's periphery.

BACKGROUND

Most internal combustion engines regulate the flow of inlet and exhaust to and from the cylinder, through a combustion chamber, by means of poppet valves. An alternative means of regulating these flows is the rotary valve, and in particular the axial flow rotary valve. Although many rotary valve arrangements have been tested unsuccessfully in the past, recent developments have opened the way for the commercial exploitation of axial flow rotary valves, which have many advantages compared to poppet valves.

Axial flow rotary valves are well known and examples are described in US Patent No. 5,526,780 (Wallis) and US Patent No. 4,852,532 (Bishop). An axial flow rotary valve rotates within a bore in the cylinder head of an engine, and each port in the valve extends from a peripheral opening on the periphery of the valve to an axial opening at one end of the valve. A significant portion of each port is substantially parallel to the axis of rotation of the valve. Typically, there is a single axial flow rotary valve for each cylinder of the engine and each axial flow rotary valve incorporates both an inlet and exhaust port terminating at opposite ends of the valve. During rotation of an axial flow rotary valve the peripheral openings periodically communicate with the combustion chamber through a window in the bore of the cylinder head to allow passage of fluids to and from the cylinder via the combustion chamber. The valve opening of an axial flow rotary valve is the opening through which the fluid passes when it travels between the ports and the combustion chamber. At any rotational position of the valve,

the valve opening is the overlap area between the peripheral openings and the window.

Typically, an inlet passageway extends from the axial opening at the end of the inlet port of an axial flow rotary valve. This passageway opens to atmospheric pressure, or in the case of a supercharged or turbocharged engine this passageway opens to the source of pressurised air. The passageway may contain a throttle valve. The combination of the inlet passageway and the inlet port forms an inlet tract. Similarly, an exhaust passageway, usually in the form of an exhaust pipe, typically extends from the axial opening at the end of the exhaust port to atmosphere, and the combination of the exhaust passageway and the exhaust port forms an exhaust tract.

Likewise, the inlet tract of a poppet valve engine extends from the inlet poppet valve opening, through the inlet port and any connected passageway, to atmosphere. The exhaust tract of a poppet valve engine extends from the exhaust poppet valve opening, through the exhaust port and any connected passageway, to atmosphere. The valve opening of a poppet valve is the annular opening between the valve seat and it's mating face on the poppet valve.

The fluids occupying the tracts of an internal combustion engine are cyclically subjected to impulses from the cylinder, which create pressure pulses in the tract. These pressure pulses traverse the length of the tract at the local speed of sound creating a time varying pressure wave within it. All modern internal combustion engines utilise these pressure waves to improve the flows of fluid into and out of the cylinder. The explanation of the source of these pressure waves and how they are best harnessed in a poppet valve engine is well known in the art. In order to better explain the present invention, a brief simplified explanation of the pressure waves in an inlet tract will now be provided.

At the start of the induction stroke, the acceleration of the piston away from top dead centre (tdc) creates a negative pressure pulse in the fluid residing in the inlet tract adjacent the valve opening. This negative pressure pulse travels at the local speed of sound towards the open or atmospheric end of the inlet tract. At the open end of the

tract the negative pressure pulse is reflected as a positive pressure pulse which travels back towards the cylinder at the local speed of sound. When this positive pressure pulse reaches the valve opening it is again reflected as negative pressure pulse that travels towards the open end of the inlet tract. Depending on the length of the inlet tract and engine speed, the pressure pulse may traverse the inlet tract several times before the inlet port closes to the combustion chamber. The inlet tract length is chosen to ensure that the return of a positive pressure pulse to the valve opening coincides with the end of the inlet stroke. The presence of this positive pulse acts to increase the density of the charge being fed to the cylinder and to overcome any adverse pressure gradient existing between the cylinder and the inlet tract. Correct utilisation of the pressure wave increases the volumetric efficiency of the engine.

In high performance poppet valve engines, the inlet port is arranged such that it is as close to coaxial with the poppet valve as possible. Consequently any pulse reflected from the open end of the tract will reach all parts of the poppet valve opening simultaneously. However, in axial flow rotary valves a considerable portion of the inlet port is approximately perpendicular to the peripheral opening. Furthermore, the peripheral opening and the window in the cylinder head bore are each generally approximately rectangular in shape with the long side of the rectangle being parallel to the axis of the rotary valve. As a consequence, the reflected pressure pulse in the inlet tract does not reach all parts of the valve opening simultaneously. Instead, the pressure pulse axially traverses the valve opening at the local speed of sound and as a result, at any instant in time, a pressure gradient exists along the length of the valve opening. This situation does not exist in poppet valve engines where the tract length can be adjusted such that the peak pressure occurs at the appropriate time over the entire poppet valve opening. In the case of typical axial flow rotary valve engines, the inlet tract length can be adjusted such that peak pressure occurs over a portion of the length of the valve opening at an appropriate time, but not over its entire length at the same time.

This particular problem is amplified by the fact that in order to maximise the breathing capability of an axial flow rotary valve engine the window length and consequently the

length of the peripheral opening is generally made very long. Typically the window length may be greater than 60% of the cylinder bore size. This compares to poppet valves in a four valve per cylinder head where the valve head diameter is typically less than 35% of the bore diameter. The problem is further amplified on rotary valve engines designed for high speed where the inlet tract length required to operate at high speed is relatively short. In these engines the length of the peripheral opening represents a significant portion of the tract length. The greater this portion, the steeper the pressure gradient will be along the length of the valve opening thus reducing volumetric efficiency. In certain cases the pressure gradient can be steep enough such that air is being pushed into the combustion chamber at one end of the valve opening while at the other end air is being pushed from the combustion chamber into the port.

The peripheral openings and windows of axial flow rotary valve engines are typically approximately rectangular to maximise the valve opening area. Each peripheral opening has a leading edge and a trailing edge on opposite sides of the opening. The window also has a leading edge and a trailing edge. As the valve rotates, it opens to allow communication between the combustion chamber and a port when the leading edge of that port's peripheral opening passes the leading edge of the window. Similarly, the valve closes as the trailing edge of the peripheral opening passes the trailing edge of the window. The leading edges of the peripheral openings and the window are typically deliberately designed to be parallel to each other to maximise the rate at which the valve opens. Similarly, the trailing edges of the peripheral openings and the window are also typically parallel to each other to maximise the rate at which the valve closes.

Various rotary valves have been proposed that have peripheral openings or windows shaped other than rectangular, but none of these arrangements address, or attempt to address, the problem of the pressure gradient along the length of the valve opening of an axial flow rotary valve.

Some rotary valve arrangements have been proposed where the window is substantially round in shape. The round window is usually dictated by the use of a

'shoe' type gas sealing arrangement. These arrangements necessarily limit the opening and closing rate of the valve and consequently suffer from poor breathing capacity. In these cases, the peripheral openings and window are still typically symmetric about their respective axial mid-points.

In a few exceptional cases, asymmetric windows or peripheral openings have been proposed. These arrangements generally fall into two categories. Firstly there are arrangements where the peripheral openings or window are asymmetric for packaging or construction reasons. Secondly, there are arrangements where asymmetry has been introduced to create variation in valve timing.

An example of the first category is shown in Fig.2 of US Patent 4,022,178 (Cross et al) depicting an asymmetric peripheral opening. The shape of this peripheral opening is similar to that shown in Fig. 8 of this specification. The asymmetry results from the encroachment of the common wall between the inlet and exhaust ports into the peripheral openings in the valve. In this case, the asymmetry is limited to a small axial portion of the peripheral opening. One way of defining the degree of asymmetry of a peripheral opening is to specify the portion of its overall axial length that is symmetrical about a plane, perpendicular to the valve axis, passing through the axial mid-point of that portion. It can be seen from Fig. 2 of US patent 4,022,178 that an axial portion of the peripheral opening greater than 70% of the overall length of the opening (ignoring the corner radii) is axially symmetrical about its mid-point.

An example of the second category is US patent 4,163,438 (Guenther et al). In this case the rotary valves are axially movable. This axial movement is controlled to effect a change in valve timing. However, as the full length and width of the window cannot be utilised in these arrangements breathing is poor. It is important to note that, unlike the present invention, the rotary valves described in US 4,163,438 are radial flow rotary valves, rather than axial flow rotary valves. The geometry of radial flow rotary valves, like poppet valves, is such that they do not suffer from the problems of non-uniform pressure distribution along the valve opening. This is because the ports of a radial flow rotary valve extend from one side of the periphery of the valve to the other side without any changes of flow direction. So, like a poppet valve engine, all parts of

the valve opening are substantially the same distance to the open end of the inlet tract.

The present invention seeks to improve the volumetric efficiency of an axial flow rotary valve engine.

SUMMARY OF INVENTION

In a first aspect, the present invention consists of a rotary valve assembly for an internal combustion engine comprising a cylinder head and an axial flow rotary valve rotatable within a bore in said cylinder head, said valve having a port extending from a peripheral opening on the periphery of said valve to an axial opening at one end of said valve, said peripheral opening periodically communicating with a combustion chamber through a window in said bore as said valve rotates, said peripheral opening having a first trailing edge and said window having a second trailing edge whereby said port closes from said combustion chamber as said first trailing edge passes said second trailing edge as said valve rotates, characterised in that said first and second trailing edges are disposed such that as said port closes from said combustion chamber the instantaneous intersection point of said first and second trailing edges progressively moves away from said axial opening over at least 50% of the length of said window.

Preferably, said port is an inlet port.

Preferably, said first and second trailing edges are disposed such that as said port closes from said combustion chamber the instantaneous intersection point of said first and second trailing edges progressively moves away from said axial opening over substantially the whole length of said window.

Preferably, said first trailing edge is substantially linear and oblique to the axis of said valve, and said second trailing edge is substantially linear and parallel to the axis of said valve. Preferably, said first trailing edge is substantially linear and oblique to the axis of said valve.

Preferably, said window is substantially rectangular. Preferably, the length of said window is at least 60% of the bore diameter of the cylinder that said rotary valve assembly is adapted to suit.

In a second aspect, the present invention consists of a rotary valve assembly for an internal combustion engine comprising a cylinder head and an axial flow rotary valve rotatable about an axis within a bore in said cylinder head, said valve having a port extending from a peripheral opening on the periphery of said valve to an axial opening at one end of said valve, said peripheral opening periodically communicating with a combustion chamber through a window in said bore as said valve rotates, characterised in that every axial portion of said peripheral opening, said window or both that is longer than one half of the length of said window is asymmetric about a plane passing through the axial mid-point of said portion, perpendicular to said axis.

In one preferred embodiment, said peripheral opening has a first trailing edge and said window has a second trailing edge whereby said port closes from said combustion chamber as said first trailing edge passes said second trailing edge as said valve rotates, and said first and second trailing edges are disposed such that as said port closes from said combustion chamber the instantaneous intersection point of said first and second trailing edges progressively moves away from said axial opening over at least 50% of the length of said window.

In another preferred embodiment, said peripheral opening has a first leading edge and said window has a second leading edge whereby said port opens to said combustion chamber as said first leading edge passes said second leading edge as said valve rotates, and said first and second leading edges are disposed such that as said port opens to said combustion chamber the instantaneous intersection point of said first and second leading edges progressively moves towards said axial opening over at least 50% of the length of said window.

In one preferred embodiment, said peripheral opening is narrower at its end proximate to said axial opening than at its end remote from said axial opening.

Preferably, the width of said peripheral opening progressively decreases from a maximum at its end remote from said axial opening to a minimum at its end proximate to said axial opening. Preferably, the trailing edge of said peripheral opening is substantially parallel to said axis.

In another preferred embodiment, said window is narrower at its end proximate to said axial opening than at its end remote from said axial opening. Preferably, the width of said window progressively decreases from a maximum at its end remote from said axial opening to a minimum at its end proximate to said axial opening. Preferably, the trailing edge of said window is substantially parallel to said axis.

Preferably, said window is substantially rectangular. Preferably, said port is an inlet port.

BRIEF DESCRIPTION OF DRAWINGS

Fig. 1 is a cross sectional view of an internal combustion engine having a first embodiment of rotary valve assembly in accordance with the present invention.

Fig. 2 is a view of the cylinder head and valve, looking into the window from the cylinder side of the cylinder head, of the internal combustion engine shown in Fig. 1.

Fig. 3 is a side view of the rotary valve of the internal combustion engine shown in Fig. 1.

Fig. 4 is a projection of the inlet peripheral opening geometry of the rotary valve shown in Fig. 3.

Fig. 5 is a view of the cylinder head and valve, looking into the window from the cylinder side of the cylinder head, of an internal combustion engine having a second embodiment of a rotary valve assembly in accordance with the present invention.

Figs. 6a-6l depict various alternative shapes of peripheral openings or windows that may be utilised in axial flow rotary valve assemblies in accordance with the present invention.

Fig. 7 is a view of an inlet peripheral opening in accordance with the present invention, projected onto plane B of Fig. 3.

Fig. 8 is a view of a prior art inlet peripheral opening.

BEST MODE OF CARRYING OUT THE INVENTION

Figs. 1 to 4 depict an internal combustion engine having a first embodiment of a rotary valve assembly in accordance with the present invention. Referring to Fig. 1, rotary valve 1 rotates within bore 11 of cylinder head 9 about axis A, supported by bearings 26. Valve 1 is rotated by means not shown to be in timed relationship with piston 20 as it reciprocates within cylinder 10. There is a small clearance between the cylindrical portion 25 of valve 1 and bore 11. An array of floating seals (not shown) spans the small clearance between cylindrical portion 25 and bore 11 thus preventing the loss of fluids. Valve 1 has an inlet port 2 and an exhaust port 3. Inlet port 2 extends from inlet peripheral opening 4 on the periphery of valve 1 to inlet axial opening 6 at one end of valve 1. Exhaust port 3 extends from exhaust peripheral opening 5 to exhaust axial opening 19, at the opposite end of valve 1 to inlet axial opening 6. As valve 1 rotates, inlet and exhaust peripheral openings 4, 5 periodically communicate with combustion chamber 30 through window 8 in bore 11 of cylinder head 9. During the compression and power strokes of the engine, cylindrical portion 25 covers window 8 to prevent the escape of fluids from combustion chamber 30.

Inlet passageway 28 extends from inlet axial opening 6 to open end 29. Throttle valve 7 is mounted in inlet passageway 28. The combination of inlet port 2 and inlet passageway 28 forms an inlet tract. An exhaust pipe (not shown) extends from exhaust axial opening 19, and the combination of exhaust port 3 with the exhaust pipe forms an exhaust tract.

Fig. 2 is a view of cylinder head 9 and valve 1 looking into window 8 from the side of cylinder head 9 that faces cylinder 10. Valve 1 rotates in a direction indicated by arrow R such that inlet peripheral opening 4 (indicated by broken lines where hidden) opens then closes to window 8 as it moves from left to right as viewed, thereby opening then closing inlet port 2 to combustion chamber 30. In the position shown, inlet peripheral opening 4 is almost fully closed to window 8. The remaining valve opening 16 at this instant is the overlap between inlet peripheral opening 4 and window 8. Window 8 is rectangular in shape and its trailing edge 12 is substantially parallel to axis A. To maximise breathing capacity of the engine, window 8 is long relative to the diameter of cylinder 10 in the direction of axis A. The trailing edge 13 of inlet peripheral opening 4 is oblique to axis A by a predetermined angular amount. As valve 1 rotates and inlet peripheral opening 4 closes to window 8, the instantaneous intersection point 17 of inlet peripheral opening trailing edge 13 and window trailing edge 12 progressively moves axially away from inlet axial opening 6. Or in other words, as inlet peripheral opening 4 closes, intersection point 17 progressively moves from window end 14, proximate to inlet axial opening 6, to window end 15, remote from inlet axial opening 6.

At the start of the induction stroke, piston 20 accelerates away from top dead centre, creating a negative pressure pulse in the fluid residing in inlet port 2 adjacent inlet peripheral opening 4. This negative pressure pulse travels at the local speed of sound through inlet port 2 and inlet passageway 28 until it reaches open end 29. This negative pressure pulse is then reflected back towards combustion chamber 30 as a positive pressure pulse travelling at the local speed of sound. The pressure pulse may traverse the inlet tract several times as discussed in the background. The angle of inlet peripheral opening trailing edge 13 to axis A is predetermined such that at a particular desired engine speed the return positive pressure pulse traverses the length of window 8 at approximately the same rate that instantaneous intersection point 17 moves along window 8 as inlet peripheral opening 4 closes. Furthermore, the length of the inlet tract is chosen such that at the same engine speed, a return positive pressure pulse travels adjacent the instantaneous intersection point 17 as the pressure pulse traverses the length of window 8. This means that at each point along the length of window 8, once the positive pressure pulse has passed that point then

that point is closed to prevent the fluid flowing back out of the combustion chamber into the lower pressure that follows behind the positive pressure pulse. This relative arrangement of inlet peripheral opening trailing edge 13 and window trailing edge 12 therefore improves the volumetric efficiency of an axial flow rotary valve engine by utilising the reflected positive pressure pulse over the whole length of window 8.

Figs. 3 and 4 illustrate how the shape of inlet peripheral opening 4 is defined. Plane D is perpendicular to the axis A of valve 1 and passes through the mid-point 31 of inlet peripheral opening 4. Mid-point 31 is axially halfway between ends 32 and 33 of inlet peripheral opening 4, and circumferentially halfway between points 34 and 35, which are defined by the intersection of plane D with inlet peripheral opening trailing edge 13 and inlet peripheral opening leading edge 18 respectively. Axis A and mid-point 31 lie in plane C. Plane B is perpendicular to both planes C and D, and passes through intersection points 34 and 35. In this specification, all discussions relating to the shape of inlet peripheral opening 4 refer to its shape as projected onto plane B, as shown in Fig. 3. Likewise all discussions referring to the shape of any other peripheral opening or window refer to the shape as projected onto a plane constructed in the same manner as plane B for that particular opening.

Fig. 4 shows the specific points required to define the angular orientation of inlet peripheral opening trailing edge 13 to axis A. Axis A lies in both planes E and F, and planes E and F pass through end points 21 and 22 respectively of inlet peripheral opening trailing edge 13. Taper angle α is the angle between planes E and F.

The amount of taper angle α required to obtain the benefit of the present invention is typically small. The maximum taper angle α required for a four stroke engine can be calculated using the following formula. Maximum α = (window length L / local speed of sound) x (engine speed in rpm x 3). This assumes the pressure pulse is rectangular in shape and very narrow. In reality the pulse is neither rectangular nor narrow and consequently the required taper angle α will generally be smaller than that calculated by the above formula. The taper angle α required increases with the length L of window 8 and engine speed.

Fig. 5 shows an internal combustion engine having a second embodiment of a rotary valve assembly in accordance with the present invention viewed in the same manner as Fig. 2. The only differences between this rotary valve assembly and that of Figs. 1 to 4 are that the trailing edge 12a of window 8a is oblique to axis A by a predetermined amount, and the trailing edge 13a of inlet peripheral opening 4a is substantially parallel to axis A. As the valve rotates and inlet peripheral opening 4a closes to window 8a, the instantaneous intersection point 17 of inlet peripheral opening trailing edge 13a and window trailing edge 12a progressively moves axially away from inlet axial opening 6 in the same manner as the rotary valve assembly of Figs. 1 to 4. As such this arrangement also improves the volumetric efficiency of an axial flow rotary valve engine by utilising the reflected positive pressure pulse over the whole length of the window.

The present invention is not limited to the shape and configuration of the peripheral openings or windows shown in the two abovementioned embodiments. For example, in other not shown embodiments both the inlet peripheral opening trailing edge and window trailing edge may both be oblique to the axis of the valve and each other.

It is preferable that the intersection point of the inlet peripheral opening and window trailing edges progressively moves away from the inlet axial opening over substantially the whole length of the window as the valve rotates, as in the two abovementioned embodiments. However, arrangements where the intersection point progressively moves away from the inlet axial opening over at least 50% of the window length still improve the volumetric efficiency of an axial flow rotary valve engine. Such rotary valve assemblies have the geometrical attribute that every axial portion of the inlet peripheral opening and/or the window that is longer than 50% of the length of that opening is asymmetric about a plane perpendicular to the axis of the valve, passing through the mid-point of that portion. For the purposes of this test, the corner radii of the opening should be ignored and the geometry of the opening should be considered to be that generated by projecting the leading edge, trailing edge and ends of the opening to their intersection points.

Figs. 7 and 8 depict two example inlet peripheral openings. Consider an engine the same as that of Figs. 1 to 4 except with an inlet peripheral opening 4b shaped as shown in Fig. 7. More than 50% of the length of inlet peripheral opening trailing edge 13b is oblique to axis A and the remainder is parallel to axis A. As such, the instantaneous intersection point 17 (refer Fig. 2) progressively moves away from inlet axial opening 6 over at least 50% of the length of window 8. Applying the above geometrical test to inlet peripheral opening 4b, H represents any axial portion of inlet peripheral opening 4b that is greater than 50% of L in length. M is a plane perpendicular to axis A that passes through the mid-point of portion H. It is clear from Fig. 7 that portion H is asymmetric about plane M regardless of where along the length of inlet peripheral opening 4b portion H is chosen.

Next, consider an engine the same as that of Figs. 1 to 4 except with an inlet peripheral opening 4c shaped as shown in Fig. 8. Inlet peripheral opening 4c is similar to that of the prior art in that only a small portion of inlet peripheral opening trailing edge 13c is oblique to axis A. Again, H represents any axial portion of inlet peripheral opening 4c that is greater than 50% of L in length. It is clear from Fig. 8 that portion H as shown is symmetric about plane M and therefore such a rotary valve assembly does not meet the above geometric test. Therefore such an engine would not have any appreciable improvement in volumetric efficiency over the prior art.

The volumetric efficiency advantages of the present invention may be further enhanced by disposing the leading edges of the inlet peripheral opening and window such that as the inlet port opens to the combustion chamber, the intersection point of these trailing edges progressively moves towards the inlet axial opening. In the prior art where both the inlet peripheral opening leading edge and the window leading edge are parallel to the axis of the valve, the downward motion of the piston as the inlet port opens imparts an impulse to the fluid in the inlet port that is uniform along the length of the window. The negative pressure pulse that travels along the inlet tract resulting from this arrangement can be thought of as the combination of an infinite number of small pulses starting at different points along the length of the window that will each reach the open end of the inlet tract at a slightly different time. The pressure pulse as a whole is therefore broad, rather than sharply defined. If however, the

intersection points of these trailing edges progressively moves towards the inlet axial opening then the arrangement can be designed such that each small pulse along the window reaches the open end of the inlet tract at approximately the same time resulting in a sharper pressure pulse that may be better used to improve the volumetric efficiency when it is reflected back as a positive pulse. The shapes and relative orientations of the leading edges to achieve an intersection point that progressively moves towards the inlet axial opening are similar to that described for the trailing edges, except mirrored about the valve axis.

The trailing edge of the exhaust peripheral opening may also be arranged such that the instantaneous intersection point of the trailing edges of the exhaust inlet peripheral opening and the window progressively moves away from the exhaust axial opening as the exhaust port opens, in a similar manner as described in relation to the opening of the inlet port. However given that the window length is generally short compared to the length of the exhaust tract the benefit will be of a lower order, compared to applying the invention to the inlet port.

Figs. 6a-6l depict various alternative shapes of peripheral openings or windows that may be utilised in axial flow rotary valve assemblies in accordance with the present invention provided that the instantaneous intersection point of the trailing edges of the peripheral opening and the window progressively moves away from the axial opening of the port as the valve rotates, or the instantaneous intersection point of the leading edges of the peripheral opening and the window progressively moves towards the axial opening of the port as the valve rotates, over at least 50% of the window length. The examples shown here are not exhaustive. It should be noted that the shapes shown in Figs. 6a-6l all have the geometrical attribute described above that every axial portion that is longer than 50% of the length of that opening is asymmetric about a plane perpendicular to the axis of the valve, passing through the mid-point of that portion

It should be noted that the invention also applies to engines having more than one axial flow rotary valve per cylinder, or axial flow rotary valves where the inlet and exhaust ports are in separate axial flow rotary valves.